THE TEMPERATURE AND MOISTURE EFFECTS OF CERTAIN MULCHING MATERIALS ON WARM SEASON CROPS

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ABSTRACT

The influence of certain soil mulching materials upon soil moisture, soil temperature, nutrient levels and plant development was studied during a period from 1949 to 1951. A series of field trials, using a randomized block design and six replicates, was conducted with three warm season vegetable crops (tomatoes, peppers and cucumbers) and three treatments (asphalt sheathing paper, wood planer shavings and no mulch). Soil moisture was determined from tensiometer readings, and temperature from recording and direct reading apparatus.

Results indicated that the use of paper mulch compared to the bare soil treatment caused a general and stable increase at a soil depth of three inches, whereas the no mulch and shavings comparison showed as definite a decrease in soil temperature, due to the use of the latter material. Both increases and decreases were of the order of 10° F.. Soil moisture was retained longest under shavings, and in general the bare soil lost the greatest amount of soil moisture. Hail interfered with plant growth and fruiting records in 1949 and 1950, but the 1951 records show a substantial increase in growth and fruit production on the paper mulch plots. Using shavings resulted in a severe depression of growth, although no symptoms of plant toxicity were observed.

It is assumed that the favorable influence of

asphalt paper as a soil mulch is largely due to its dark colour and consequent high absorption of solar radiation. It is of particular interest that the paper treatment was very effective in promoting most rapid growth and heavier fruiting during the 1951 summer, which was an unusually cool, cloudy season. There was no evidence that either mulch treatment affected the maturity rate of fruiting.

THE UNIVERSITY OF ALBERTA

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INTRODUCTION

Originally, the term "mulch" meant merely an application of manure or other loose material such as straw or leaves, spread thickly on the surface of the ground around newly planted trees and other plants. Such plants were usually of a perennial nature and the purpose of the mulch was to protect plant roots from the drying effects of wind and sun, In present day agricultural usage, however, a mulch may be defined as any artificial modification of the soil's surface. These modifications include the soil mulch achieved by recommended cultivation procedure, the straw mulch of special utility in strawberry culture, mulches laid down as winter protection in the colder areas of the world, and the impervious paper mulch used in the pineapple industry of the Hawaiian Islands.

Mulches applied to the surface of soil exert effects upon the soil enviroment. These effects are brought about by the ability of the mulch to conserve the soil moisture and raise or lower the soil temperature. The addition of organic matter raises the soil humus content, which in turn affects the soil structure. Also, this organic matter decomposes in the soil and increases the available nutrients in the soil.

Investigators have shown that plants vary in their

reaction to mulching. Differential responses have been shown to depend largely upon the climatic conditions and the type of plant grown under the mulch, as well as upon the physical characteristics of the mulch itself.

The present study is mainly concerned with evaluating the effect of certain types of mulches upon warm season crops in the north central Alberta area. The successful growing of these crops in this area is hazardous even under good weather conditions, because of the very short frost free season and generally cool nights during the growing season. It was thought that mulching the soil with black paper mulch might change the soil enviroment enough to have the effect of speeding plant maturity.

LITERATURE REVIEW

Many different types of materials have been used for mulching, including barnyard manure, seaweed, straw, wood shavings and sawdust, grass clippings, glass wool, pine needles, peat moss and paper. These materials have been used successfully on a great variety of plants. Bushnell and Weaver (9) have reported the use of straw as a mulch for potatoes. Isenberg and Odland (23) used sawdust, cow manure and straw on such crops as cucumbers, tomatoes and sweet corn. Stewart et al (45) of Hawaii used black paper as a mulch for pineapples. Flint (15) used this paper on a

large number of vegetable crops in the United States. The use of straw and sawdust as mulches for strawberries and raspberries has been long established as a good practice.

The Effect of Mulch Upon Soil Moisture

It would appear that the main object of applying a mulch to horticultural crops has been to conserve moisture. This influence assures a more constant supply available to the crop throughout the season. The ability to do this will vary with the different types of mulch materials. Harris and Yao (19) found that there was a difference of 54.1 percent in soil moisture loss between straw, the most effective material, and manure, which was least effective in conserving moisture. Wood shavings, grass and hay were found to be intermediate in this respect.

The absorbing power of the mulch material determines its ability to withdraw moisture from the soil. This moisture is subsequently lost to the atmosphere through evaporation. The moisture content held by manure was estimated at 144.7 percent of its dry weight while the moisture held by the straw was found to be 11.8 percent of its dry weight. Therefore, an efficient mulch material must be one which does not absorb or retain moisture readily and forms practically no capillary system within itself. This will explain the reports of Millar and Turk (32) that peat had an adverse effect upon moisture absorption by the soil because the moisture was taken up or absorbed directly from rainfall by the mulch. It was then

evaporated to the air before ever reaching the underlying soil.

The idea of interrupting the capillary pull of the surface soil on underlying moisture is the principle involved with the dust mulch. However, Shaw (39) has stated that the only situation when this type of mulch would be very effective in reducing loss of water by evaporation would be when the water table was very close to the surface. He suggested that the problem under these conditions would be more likely to be drainage, rather than conservation of soil water. Further to this, McCall (29) reported that the dust mulch has an inhibitory effect upon current moisture absorption under conditions where individual rains were not heavy enough to penetrate the mulch.

A good number of mulch materials have proven advantageous in conserving moisture. Harris and Yao (19) have reported that an effective mulch of straw one inch thick was capable of retaining 60 percent more moisture than the unmulched soil. Stewart et al (44) found that a black paper mulch used with pineapples in Hawaii conserved a noticeable amount more moisture than did the adjacent bare soil areas. Flint (15) suggested that the paper mulch distributed the current rainfall moisture to the advantage of the plants. The water gained by rainfall or sprinkling is carried by the paper directly to the immediate plant root area. On the bare soil, a light rain usually moistens the whole superficial layer of soil, and this moisture is quickly lost through evaporation. Alfred Smith (41) found that moisture conservation due to paper mulching did not extend

below six inches. Magistad et al (28) reported that bagasse, which is crushed sugar cane, was more effective in conserving soil moisture than was paper mulch under Hawaiian conditions. Porous soil mulches, such as straw and sawdust were found by Turk and Partridge (47) to facilitate easier infiltration of rainfall moisture into the soil.

Temperature Effects

The realization that certain types of mulching materials made favourable modifications in soil temperature levels came with the use of paper mulch on sugar cane in Hawaii. Eckart, as reported by Flint (15) noticed a favourable growth increase in cane on the mulched rows as compared to the adjacent bare soil rows. This was attributed to higher temperature and moisture due to the effect of the black paper mulch. Stewart et al (45) did tests with pineapple using similar black paper. The workers reported, that during clear weather, there was an increase in temperature at the four inch level under the paper, of the order of four to six degrees F. Their report also shows that for a short time after heavy rains the bare soil had a higher temperature than the mulch. This suggests that the temperature difference under the paper mulch was directly related to the effect of the sun's rays. The effect of the sun radiation is well illustrated in a report by Flint (15). It was found that the increase in temperature of the soil under paper, over the bare soil was ten degrees F. during sunny periods, and was three degrees F. without direct radiation.

The influence of the colour of the mulch is indicated by the work of Alfred Smith (41). Black paper mulch was compared to grey-coloured paper. The black paper was found to raise the temperature considerably higher than did the grey. Smith suggested that the black paper absorbed the sun's rays more readily. This was further substantiated by McCalla (30) who used a bright straw mulch in comparison with a dark straw mulch and the bare soil. It was reported that the bright straw mulch, which reflects the most light, warmed the least, while the bare soil which reflected the least light, warmed the most. The dark mulch was intermediate in temperature reaction.

The magnitude of the increase in temperature, due to paper mulching, has been shown to vary depending upon climatic conditions. Shaw (38) of California, reported that the paper mulched soil was warmer 62 percent of the time, while the bare soil plots were warmer 28 percent of the time. Alfred Smith (41) working in the same general area the following year, reported results which differed with those of Shaw. The day-time average soil temperatures at the three inch level on the black paper mulch was 5.4 degrees F. higher than that on the bare soil. Night time average temperatures on the paper mulch were 6.4 degrees F. higher than the bare soil. At no time during the season was the temperature on the paper mulch lower than that on the bare soil.

These differences in results might suggest that the

effect of paper mulch in increasing soil temperature will vary from season to season in the same area. Stewart et al(45) in Hawaii found that paper mulch was warmer than no mulch approximately 90 percent of the time during their experiments. Most of the mulching materials exclusive of paper tend to reduce the temperature of the soil. Isenberg and Odland (23) found that such materials as sawdust, grass clippings, cow manure etc. lowered the soil temperature below that of the bare soil. Also the range of daily maxima and minima was found to be much narrower. This indicates an insulating effect by the mulch which must be coupled with the observed heat absorption or reflection influence.

Albrecht and Uhland (3) reported temperatures which were 10 degrees C. cooler at the two inch level under straw mulch than those on bare soil. McCalla and Duley (31) found that the difference between straw mulched and bare soil on their plots was from 10 degrees to 17 degrees C. depending upon the thickness of the mulch.

The effect which mulches have on soil temperatures may be reflected in good or poor growth of plants. A suggestion as to how temperatures affect plant growth is indicated by Schroeder (36). It was found that the critical temperature for water absorption in the roots of cucumbers was between 60 to 70 degrees F. This worker implied that leaf and fruit injury in the late season could be traced to a water deficiency in the effected parts. Carter (11) found

that the temperatures below 12 degrees C. and above 37 degrees C. restricted the production of dry weight material in soya beans. These are two instances of many which indicate that soil temperature is a major factor in the over-all soil environment of the plants.

Effects on the Other Soil Properties

The fact that most mulches become incorporated in the top soil, suggests that the materials of the mulch might exert some effect upon such properties of the soil as structure, reaction, fertility and aggregation. Bollen and Stephenson (8) working with straw, hay and sawdust mulches reported no effect on soil reaction with sawdust. There was some indication that the hay and straw might have reduced the acidity of the soil next to the mulch. Subrahmanyan (46) reported that high moisture contents effected an increase in pH in soil. This suggests that the higher level of moisture under mulch might have an effect on soil reaction similarly.

The type of soil aggregation determines the soils structure. Anything which affects aggregation formation adversely will result in poor structure. This in turn results in poor growing conditions even though nutrients are present in adequate amounts in the soil. Hubbell and Gardener (21) found that a high moisture content in the soil reduced aggregation. Alderfer and Merkle (4) stated that manure applied to the soil gave the largest number of large sized aggregates, followed by sawdust, oak leaves and corn stover

respectively. However, these workers qualify their conclusions by suggesting that the chief value of these mulches was in soil protection rather than any effect there might be in changing the fundamental structure of the soil. Stephenson and Schuster (42) (43) found that straw increased the water-soluble aggregates. This was thought to be caused mainly by the increase in organic matter from the rotting mulch. Van Doren and Stauffer (48) also reported that straw mulch very definitely favoured aggregation of their soil. Baver (5) states that one of the agencies in aggregate formation is alternate wetting and drying of the soil. There is the possibility then, that the action of the mulch in keeping the soil moisture relatively constant throughout the growing season, could be detrimental to soil aggregation. The paper mulch has not been cited as demonstrating any effect upon soil aggregation formation or upon soil structure.

The presence of nutrients in the soil, in a readily available form to support good growth, reflects the fertility of that soil. The effect of mulching upon this fertility has been studied by a number of workers. Albrecht (2) compared tillage to straw mulching in the accumulation of nitrates in the soil. The nitrates were found to be depressed by straw mulch. Later, Albrecht and Uhland (3) continued this investigation. Consideration was given to isolating the factors which caused the relative lack of nitrogen under straw mulch. The conclusions were that lower temperature, higher moisture

and also poor tilth under the mulch, were the main causes. Albrecht (1) quoted Garney and Metzler as saying that the optimum moisture for nitrate production in the soil was reached when the soil contained approximately 25 to 35 percent of the total amount of moisture it will hold. At variance with the foregoing were the results reported by Beaumont (6). He recorded a larger accumulation of nitrates under straw mulch as compared to bare soil, and offered the explanation that his soil was loose, light and well drained, as compared to the heavy soil used by Albrecht. There was, however, no mention of how long the mulch was laid down before the nitrates were determined. Beaumont and Crooks (7) reported that straw mulch accumulated nitrates slowly during the first three years, but in the fourth year after mulching, nitrates were accumulated in large amounts.

Lyon and Buckman (27) stated the responsibility for the supression of nitrates under mulch lies with the nitrogen-carbon ratio. The addition to the soil of sugars, cellulose or other substances with a wide nitrogen-carbon ratio causes a disappearance, wholly or in part, of the nitrates originally present if the conditions of decay are favourable. This disappearance does not mean that nitrates are not being formed but rather that they are being assimilated as quickly as formed. The added carbohydrate material supplies energy material for a tremendous multiplication of the all-purpose organisms in the soil. The synthesis of new protoplasm demands nitrogen, so,

all that is available in the soil is used up by the micro-organisms. There is little chance of nitrate accumulation. Much decay of the material must take place before the nitrogen-carbon ratio is again such, that nitrates may be accumulated.

Moore and Beaumont (34) estimated the percentage carbon and nitrogen at the various levels of accumulating mulch. A table of their results is presented.

Table I. C/N Ratios at Different Levels of Accumulating Mulch Material.

Material	Total C.%	Total N.%	C/N Ratio
Fresh Mulch	44.96	1.20	37.5 : 1
Top of mulch	43.61	1.72	25.4 : 1
Middle of mulch	37.29	2.90	14.9 : 1
Bottom of mulch	24.39	1.72	14.2 : 1

This illustrates effectively the difference in the nitrogen-carbon ratio between the fresh mulch and decayed bottom layer.

Turk and Partridge (47) used a number of different mulches on orchard soils. These included a gravel mulch. They found that this material, which does not add any carbonaceous material to the soil, depressed the nitrates. The opinion expressed was that lack of aeration was the main factor, with the possibility that a lower temperature also had an effect. Mooers et al (33) considered that the depressing effect of mulch upon soil nitrates was not only due to lack of aeration but also because of soluble

derivatives leached into the soil from the mulch materials. It is obvious from the foregoing that there is more than one probable effect of the mulch upon soil nitrates, and that the physical nature of the soil itself is an important consideration.

Paper mulch, which is not usually incorporated in the soil, has been reported also to affect the level of soil nitrates. Stewart et al (45) found the level of nitrates under paper mulch was much higher than it was on the bare soil. Flint (15) did soil analyses upon mulched and unmulched areas planted to corn. The soil was a clay of poor fertility. There were no differences in nitrates in the two treatments. However, plant analysis showed the mulched corn to be very high in nitrates, whereas the control plants showed no excess in nitrates. This would seem to indicate that there were more nitrates available for the plants in the mulched soil. Alfred Smith (41) found no consistent differences in nitrates between paper mulched and bare soil, but made no tissue analyses from plants produced under the two conditions.

Lyon and Buckman (27) state that the most optimum temperature for the process of nitrification is from 80 to 90 degrees F. Russel and co-workers (35) studied the rate of nitrification from five degrees C. to 55 degrees C. They found that nitrification was at its peak at 35 degrees C. and at 55 degrees C. nitrification ceased altogether. Fuller and Jones (16) found that although nitrates were reduced by adding cellulose to a soil up to a temperature of 20 to 25 degrees C.,

above this temperature the nitrates were higher than their original level, indicating a speed up of nitrification at these higher temperatures. This evidence indicates a positive relationship between nitrates and soil temperature, until a high soil temperature is reached.

Such mulches as straw and sawdust, which reduce the average soil temperature because of a reduction in absorbed light rays, might possibly have a depressing effect on available nitrogen because of these lowered temperatures. Conversely, paper mulch, which has been shown to raise the temperature of the top soil under it, should bring the temperature closer to the optimum for highest nitrate production.

Any factors which limit the microorganism population in the soil must necessarily limit the production of nitrates. Subrahmanyan (46) found that very high moisture contents in the soil reduced bacterial numbers. Eggleson (13) found no positive relationship between the number of bacteria present in the soil and moisture and temperature variations. It was suggested that there might be an indirect effect by the variations affecting growth of vegetation which supplies energy materials for the microorganisms. Greene (17) has reported that nitrogen fixation by Azotobacter was greatest at 32.5 degrees C. The fixation was much reduced at temperatures below 18 degrees C.

The availability of potassium and phosphorous in the soil is also affected by mulching. Holmes (20) found that mulching increased the mineral, especially the phosporous and

potassium, content in tomatoes. Latimer and Percival (25) found that hay mulch increased the amount of available phosphorous, magnesium and potassium. Emmett and Ball (14) have reported that wetter soils did not favour the availability of potassium. The supply of phosphate varied directly as the moisture, after the initial supply of phosphate in the soil was exhausted. It does seem probable that any modification in the soil's environment which affects one element in the nutrient balance will indirectly affect the others also, and will certainly affect the nutrient balance.

The Effect on Growth and Yield of Crops

Clark (12) used salt hay as a mulch for raspberries. He reported significant yield increases for the mulched areas. Bushnell and Welton (10) recommended the use of a straw mulch with potatoes in areas where temperatures are very high at the time of tuber set. The increase in yield was of the order of 50 bushels per acre. Bushnell and Weaver (9) found that mulching potatoes at seeding depressed growth and yield. The mulch application applied when the shoots were just up, gave 60 bushels per acre increase. Holmes (20) reported that mulches of shaving, rye straw and sugar cane improved the content of carotene and soluble solids in tomatoes. Latimer and Percival (25) found that hay mulch gave better growing conditions for apple trees than did sawdust. Harris (18) found that sawdust gave large increases in strawberry yield over no mulch in the second year after mulching. This increase was attributed to a favourable

change in the physical condition brought about by the sawdust. Isenberg and Odland (23) working in Pennsylvania, reported increased yields of cucumbers, corn and tomatoes with the mulch materials straw, sawdust, cow manure and leaves. Stewart et al (44) found that the growth of paper mulched pineapples was much more vigorous than in the adjacent no mulch plots. Alfred Smith (41) reported slight increases in yield on paper mulch of potatoes and yalo. Shaw (38) noted that in California there was no apparent increase in yield of potatoes, beans and milo, by the application of paper mulch. Flint (15) did experiments on a large number of crops with black paper mulch. It was found that the mulch gave a favourable increase in yield to the majority of these crops. For example, cucumbers, corn and carrots on paper mulch gave yields approximately six times those obtained on bare soil. Flint also found that a number of crops were brought to maturity earlier by this mulch. Leslie (26) has reported that such vegetable crops as lettuce, cauliflower, cucumbers and melons were benefited by the application of paper mulch under Manitoba conditions. Also, it was found that celery was affected adversely by this practice. Hutchins (22) suggests that although the paper has a beneficial effect upon yield in a majority of cases, economic factors narrow down the type of crop upon which it may be used commercially. Those of a high per acre value and of a warm season type were considered by Hutchins to be best suited for this practice.

Value in Weed Suppression

Bushnell and Weaver (9) found that 10 tons of straw per acre would not keep down perennial weeds. A number of workers (15) (45) (38) have found paper mulch to be extremely efficient in reducing the labor needed for weeding. Sawdust is intermediate between straw and paper unless a coating deeper than two inches is applied.

A Comparison of Field Methods of Measuring Moisture

The relative merits of the various methods of determining moisture levels in the field were reviewed, in order to evaluate the reliance which might be placed in the tensiometer method of estimation. The gravimetric method was considered most accurate by Kelley (24). However, it has disadvantages for field work. These are length of time required, labor involved and equipment needed. Scofield (37) found that tensiometers gave very precise and useful information of the available moisture in the soil. Veihmeyer (49) found tensiometer readings paralleled actual moisture available to plant life. Kelley (24) reported the tensiometer was accurate within its range, but that this range was too narrow. These instruments can only measure to 850 centimeters of mercury. The soil moisture is still relatively high at this point. Slater and co-workers (40) found the gravimetric plugs best for low moisture content readings. Kelley (24) found these plugs unreliable in field practice. Kelley also found that the Boyoucos electrical resistance blocks were best for tensions above one atmosphere, if there was no

excess of salts in the soil. Slater (40) found these instruments insensitive at higher levels of moisture.

The general opinion of the workers (24) (49) (37) was that no one instrument was good for all moisture levels. Tensiometers were found most accurate at high moistures, while the Boyoucos blocks were best of those used at low moisture levels.

EXPERIMENT I - 1949

MATERIALS AND METHODS

The tests carried out in 1949 were of a limited scope. They were designed to give some indication of the effect of black paper mulching upon warm season crops in the north central Alberta area.

The following types of mulch were used:

1. Heavy black asphalt coated building or sheathing paper laid down in strips 36 inches wide and 11 feet long with "V" shaped cuts for planting of test plants.

2. Planer shavings laid down at a depth of two inches over the whole area.

3. A check area where no mulch was employed.

Three kinds of warm season crops were used:

1. Tomato - variety L3700 strain I
2. Pepper - variety Windsor A
3. Cucumber - variety Mandarin

The cucumbers, peppers and tomatoes were each planted in triplicate rows, running right through the areas of no mulch, paper and shavings, respectively.

Soil moisture determinations were made by means of vacuum gauge readings on Rogers tensiometers #. One of these instruments was placed in a central spot in each of the three treatments. Due to late arrival of the tensiometers, no readings were taken until the last week in July. Readings

- Obtained from Gallenkamp Ltd., Sun Street, London, England.

were taken thereafter until the first frost on September 10th, at bi-weekly intervals.

The conditions of this 1949 season were generally so dry, and the frost free season so short, that it should probably have been ideal for a test such as this. However, no yield results could be obtained because of the interference of a severe hailstorm on July 16th. The storm damaged the plants enough to make any yield data taken, unreliable. However, rapid plant recovery allowed observation of growth differences.

No thermographs were available for the trial, and soil temperatures could not be taken at definite periods because of the press of other duties. These were recorded irregularly during the month of August by using direct reading Taylor dial thermometers.

An application of 11-48-0 fertilizer was applied to the whole area at the rate of 30 lbs. of actual nitrogen per acre. This was done to insure an ample supply of the necessary nutrients in the soil for normal plant growth.

EXPERIMENT I RESULTS

The damage caused by the hailstorm prevented the recording of any useful yield results for this season. Temperature and moisture differences under the treatments were recorded.

Although the number of temperature readings taken was very inadequate, Table II does indicate that definite

differences were observed.

Table II. The Averaged Temperature Readings for the Month of August 1949, in Degrees C., an Average of 10 Readings, at the 3 inch level, under the treatments.

	No Mulch	Shavings	Paper
8 A.M. Readings	19.2	16.8	19.3
12 A.M. Readings	24.3	20.2	28.8
3 P.M. Readings	24.6	19.0	29.0

These data indicate a raising of the temperature by the paper mulch. The shavings mulch kept the soil mulch much cooler than the other treatments.

The moisture readings allow an estimation of the relative efficiency of the two mulches in conserving moisture. These are shown in Table III.

It was observed that recovery from the hailstorm was much more rapid and complete on paper mulch. It was also noted that the plants on the shavings mulch showed a yellowing which resembled early stages of the chlorosis usually associated with nitrogen deficiency.

Table III. Moisture Meter Records# in Cm/Hg at Five Inches Depth.

Date - 1949	No Mulch	Shavings	Paper
July 25	5	5	8
July 30	7	7	7.5
Aug. 2	8	8	8
Aug. 5	8.5	8	8
Aug. 9	10	8	8
Aug. 15	12	9	8.5
Aug. 23	19	9	9.5
Aug. 25	22	8.5	10
Aug. 29	9	7	8
Sept. 3	11	8	8
Sept. 6	13	9	9
Sept. 9	16	8.5	10
Mean	11.5	7.8	8.6

#--Tensiometer readings and percentage moisture are in an inverse relation to one another.

EXPERIMENT II - 1950

MATERIALS AND METHODS

In 1950 the trials were made more elaborate and the area was increased to three tenths of an acre. Three separate tests of identical treatments and equal size were involved, differing in the kind of vegetable grown as test material. The three vegetables (L-3700 tomato, Mandarin cucumber and Windsor A pepper) were treated separately since this method allowed a simple variance analysis to be carried out for each vegetable. The treatments were:

1. Asphalt-coated black paper in strips three feet wide by 20 feet long. This paper was held in place by covering the edges with soil from the "between paper strip" area.

2. Planer shavings spread over the plots, 2 inches deep.

3. Bare soil plots designated as "No Mulch".

The plots were made 12 feet by 20 feet. Three of these plots constituted a block. The treatments were placed in each block at random and each block and plot was replicated six times. A clear representation of the plot arrangement is shown in Figure 1.

Ammonium nitrate was applied only to the shavings mulch plots. This was done to offset the known effect the shavings have in reducing available nitrogen for one to two

Fig.1. A view of the 1950 experimental area, showing the random arrangement of the plots.

seasons after application. This fertilizer was applied at the rate of 50 lbs. per acre in four equal applications, approximately 15 days apart beginning June 15.

The cucumbers were seeded directly into the slits made in the paper and normally, under shavings and no mulch. Wax paper hot caps were used to encourage early development. The tomatoes and pepper plants were transplanted to all treatment plots at normal transplanting time. Although the seed bed appeared to be near the optimum for moisture at the time of planting, the usual precaution of supplying water to the transplants was taken. The three vegetables were set in the row at the usual distance recommended for each. The rows on the paper were situated midway across the three foot width. This gave equal widths of paper on both sides of the plants. Planting dates for the trial were June 7 and 8 for cucumbers, June 9 and 10 for tomatoes and June 11 and 12 for peppers.

Soil moisture readings were recorded three times weekly for the months of June, July and August. These were obtained from three Rogers tensiometers placed at random on one block of tomatoes. The porous cups of these meters were placed at the five inch level in the centre of a row under each treatment.

The tensiometers were calibrated for the percentage moisture in the soil of the experimental area. This was done by removing a section of the soil, in profile, and placing it

in a specially built box in the greenhouse. The tensiometer was then placed in the soil in the box at the same level as it was in the field. The soil was saturated with water, and then allowed to dry out normally. While the soil was drying out, gravimetric soil moisture determinations were taken in triplicate, at every change of five centimeters of mercury on the moisture meters. The graph of this calibration is presented in Figure 2.

Temperature records were taken by means of recording thermographs. These records were limited by the number of thermographs available. Soil temperatures were recorded on the pepper plots at the three inch level under no mulch and paper mulch during the month of July. A record of the temperatures in the soil under the shavings mulch was obtained during the month of August. In order to supplement these records, temperatures were taken on one block of each vegetable with Taylor dial thermometers at one and three inches below the surface of the soil. Air temperatures were also recorded, one at ground level, and then, a reading for the whole area at four feet above ground. These readings were taken 12 times during one 24 hour period in July and another in August. This 24 hour period was chosen arbitrarily on such a day as gave promise of being a normal summer day for this area.

Quick soil analyses for nitrates, phosphates and potassium were taken at the beginning of the growing season, and then again at the height of vegetative growth. Composite

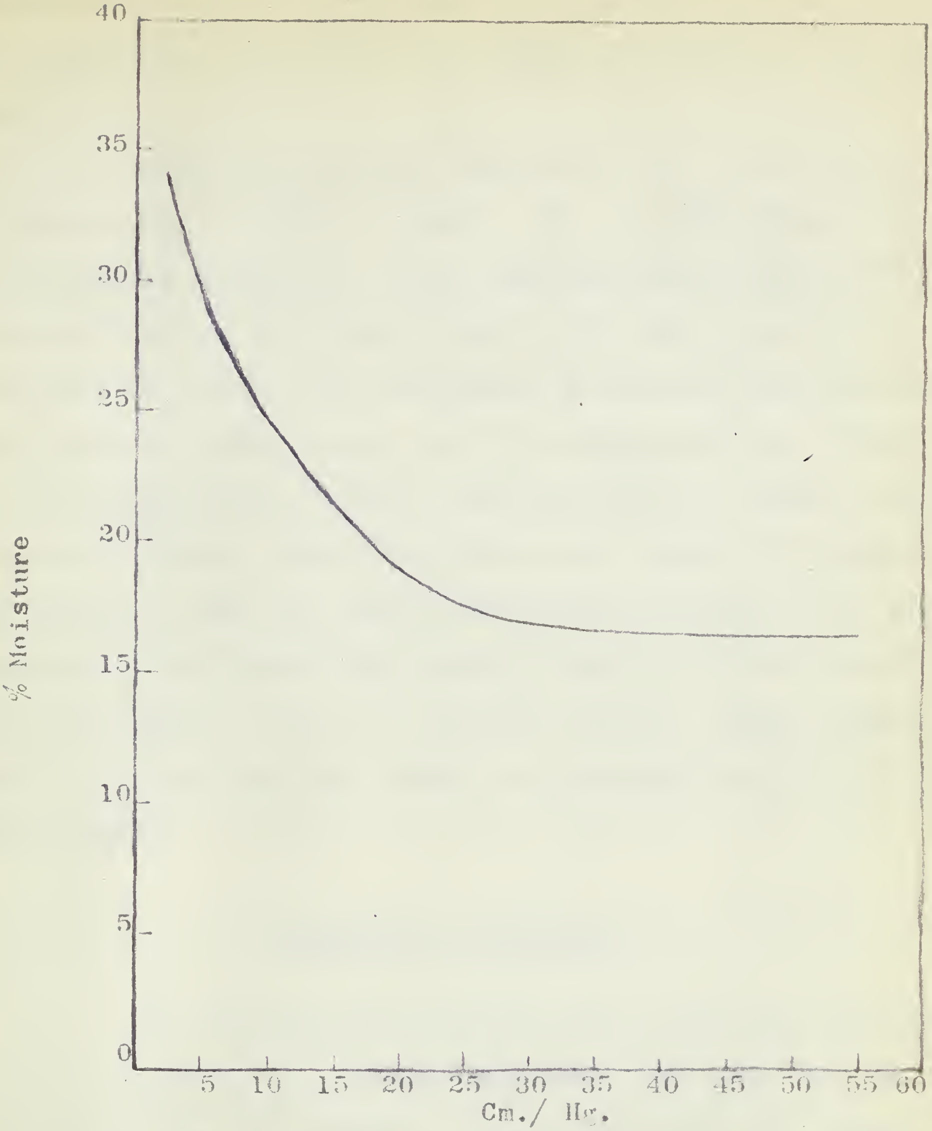

Fig. 2. Graph representing calibration of Rogers' Soil Tensiometers on Malmo clay loam, Parkland Farm, University of Alberta.

samples of the soil in each plot were gathered and used for these tests. The pH of the soils was tested at the same time.

Yields of the three vegetables were to be taken from the centre row of each treatment, with the two outside rows being left as guard rows. All other pertinent records of plant performance were to be done on the same centre rows. The plots were kept free from weeds by hand pulling on shavings and around the paper mulch, and by scraping the bare soil. At no time was weed control a serious problem, except on the "no mulch" areas. Careful attention was needed throughout the season to keep the paper mulch well anchored to the soil. Immediately following every rain the soil had to be replaced along the edges of many of the paper strips. Other methods of anchoring were tried but showed no advantages over the first method used.

EXPERIMENT II RESULTS

The growing season during 1950, like that of 1949, was dry; however, the moisture supply on the plot area was good at the time of planting. The plants made good growth upon paper mulch and no-mulch plots and did very poorly on the shavings plots. Visible differences in plant development were noticed between the paper mulch and no mulch plots at three weeks from plant setting and germination of the cucumber seeds. This was especially evident in the cucumber

plots. A very heavy and disastrous hailstorm on July 24 made yield data very unreliable, in fact, the plants were so damaged that no records of harvest were taken. Soil moisture and temperature records could of course, still be considered valid. Presumably these should indicate some of the notable changes in the production environment that were due to, and coincident with the mulching practice.

Table IV. Soil Moisture Ranges from Tensiometer Readings. Data as Cm./Hg., and for Period June - August Inclusive.

	Shavings Mulch	No Mulch	Paper Mulch
Lowest reading	2	5	7
Highest reading	12	17	14

When these readings are applied to the calibration graph in Figure 2, it is seen that the moisture percentages for all plots varied from approximately 20 percent to 31 percent. These figures indicate a fairly high moisture content in all plots throughout the season. A comparison of the treatments with respect to moisture conservation throughout the season is given in Figure 3. The soil temperature readings that were taken under paper mulch and no mulch during July were compared. The differences exhibited are outlined in Figures 4 to 7. It is noteworthy that the soil temperature

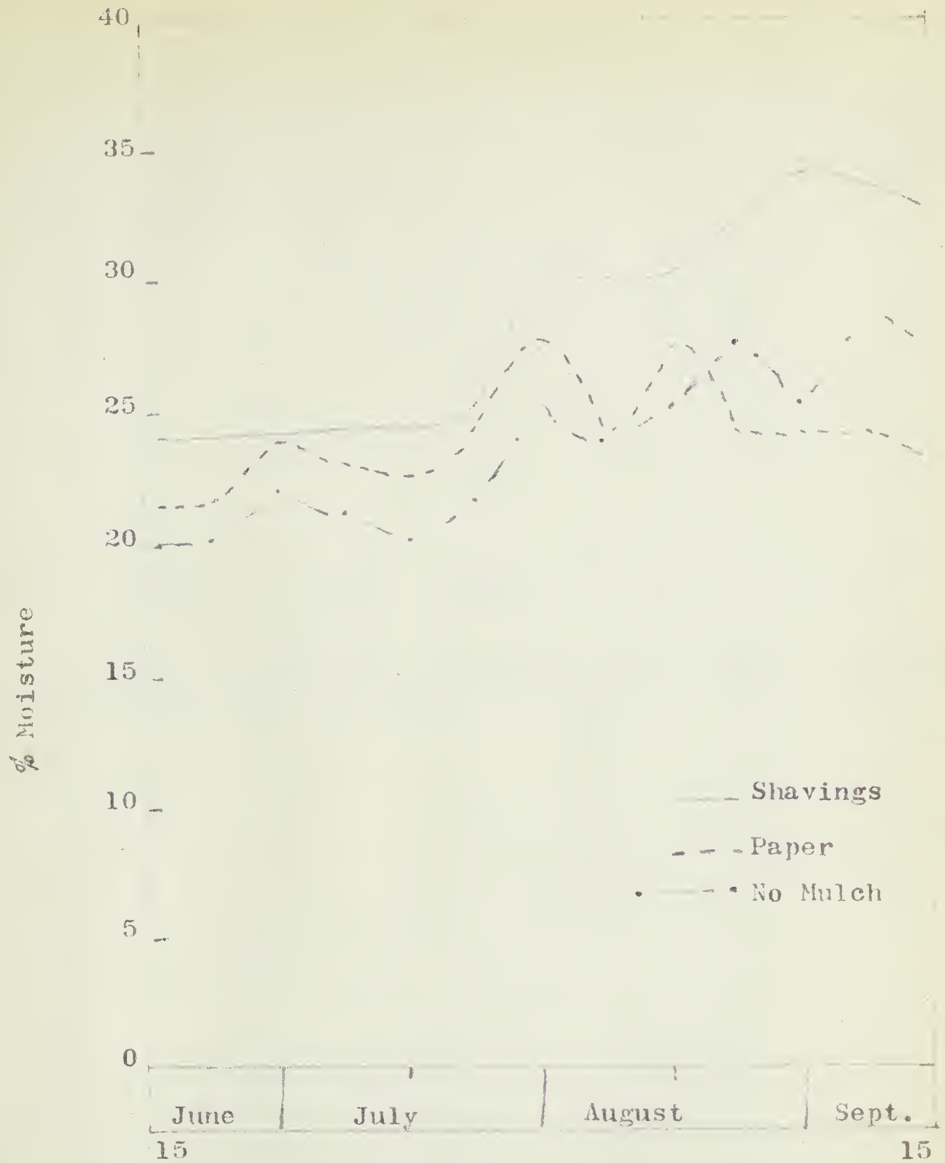

Fig. 3. A comparison of soil moisture levels, tomato crop 1950. Data evolved from tensiometer readings.

Fig. 4. Soil temperatures at 3 inch level, and air temperatures, for week of July 10 - 17, 1950.

Fig. 5. Soil temperatures at 3 inch level, and air temperatures, for week of July 17 - 24, 1950.

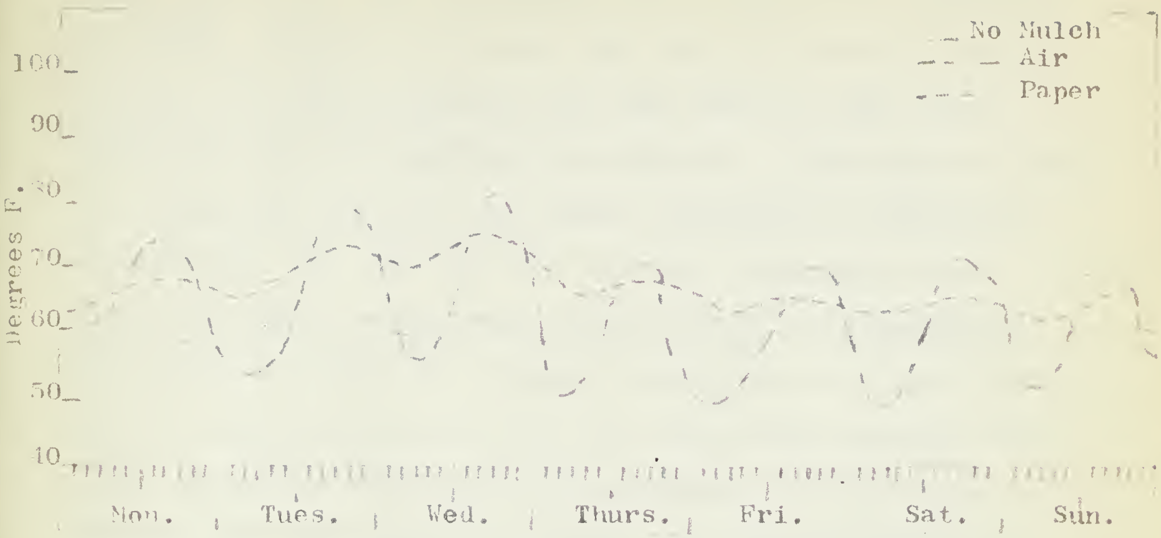

Fig. 6. Soil temperatures at 3 inch level, and air temperatures, for week of July 24 - 31, 1950.

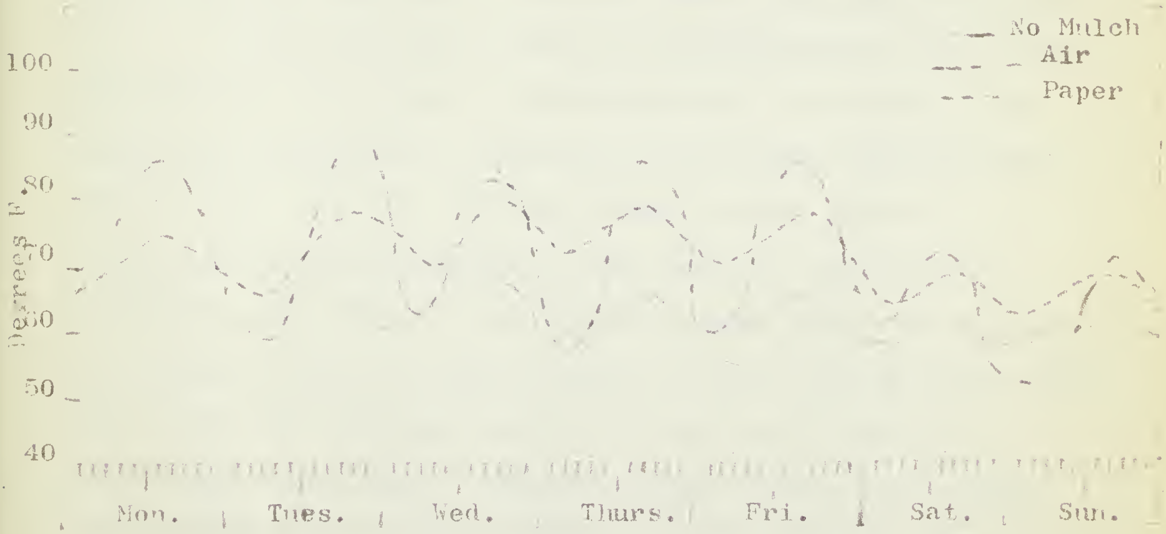

Fig. 7. Soil temperatures at 3 inch level, and air temperatures, for week of July 31 - August 8, 1950.

under the paper mulch was always higher than the temperatures under no mulch. The difference was as much as 10 degrees F. at times. Figure 8 indicates that the differences observed during the direct readings were much smaller than those obtained from the recording thermometers. The complete table of temperature data for the three treatments is presented in Appendix I. The level of the soil temperature under shavings mulch in one week during August, is illustrated in Figure 9. The corresponding temperatures for paper mulch and no mulch were spotted on this graph from readings taken with the direct reading dial themometers. It was quite obvious that the temperature under the shavings mulch was much lower than those under the other treatments. Also, it was noted that there was little fluctuation in the temperature under the shavings mulch from one time of the day to another.

The quick soil tests at the beginning of the season showed that there were no differences in the levels of the nitrates, phosphates or potassium found under the different treatments. However, the tests taken at the peak of vegetative growth exhibited a very definite pattern for nitrates. The level of the nitrates under paper was 25 p.p.m. or greater, while no mulch readings varied from 10 to 15 p.p.m. Soil under the shavings mulch was very low in nitrates. In all but three plots, there was just a trace, the highest level found was 5 p.p.m. Tables V and VI indicate the average levels for nitrate and the other elements at time of the quick analyses.

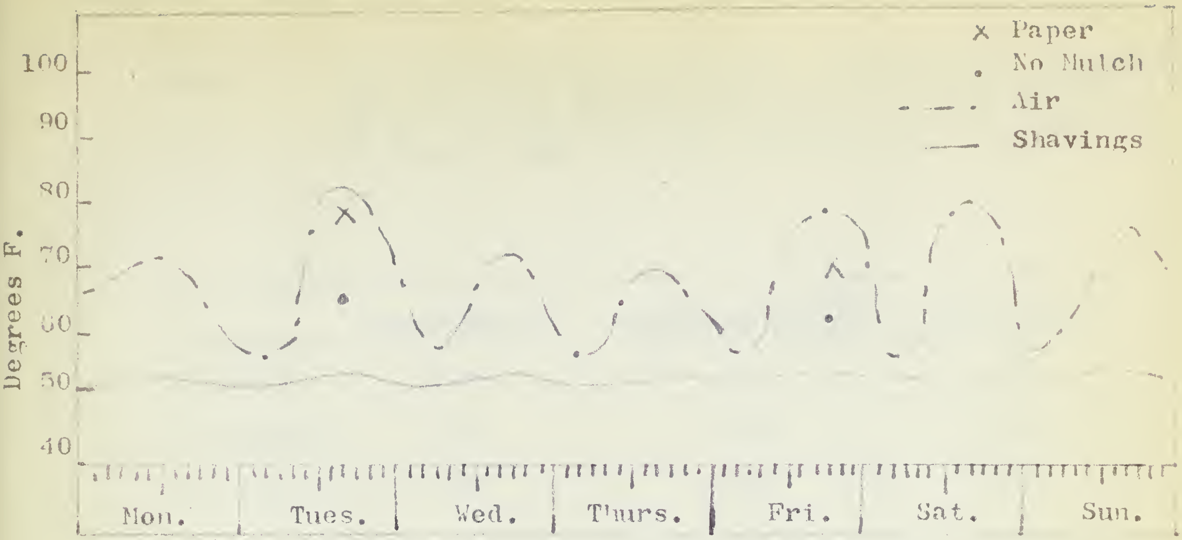

Fig. 8. Continuous soil temperatures at 3 inches , and air temperatures, for week August 8 - 15, 1950. 4 o'clock readings under paper and no mulch plots were taken on August 9 and 13.

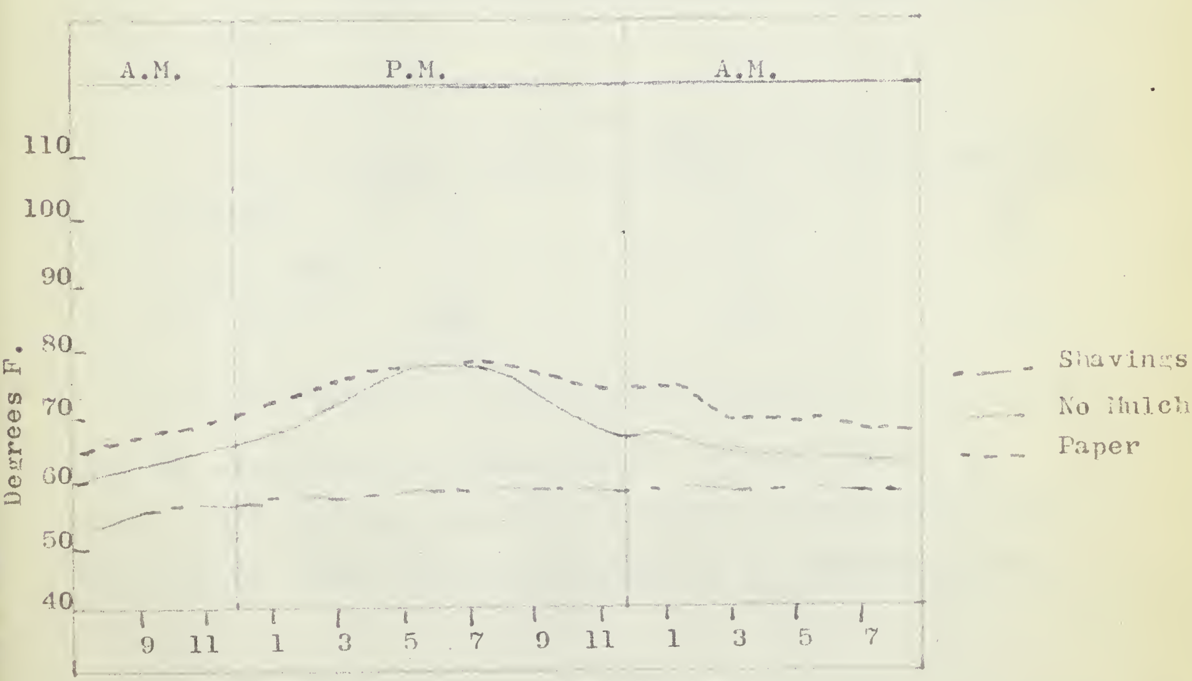

Fig. 9. Soil temperatures registered by direct reading thermometers at 3 inch level on cucumbers, July 21, 1950.

Table V. The Average Values in p.p.m. of Nitrates, Phosphates and Potassium Obtained by the Quick Soil Analysis on the 18 Plots of Each Treatment at the Beginning of Growth 1950. (Spurway technique)

	Paper Mulch	Shavings Mulch	No Mulch
Nitrates	15	14	15
Phosphates	3/4	3/4	3/4
Potassium	1/2	1/2	3/4

Table VI. The Average Values in p.p.m. of Nitrates, Phosphates, and Potassium obtained by the Quick Soil Analysis on the 18 Plots of Each Treatment at the Peak of Vegetative Growth 1950. (Spurway technique)

	Paper Mulch	Shavings Mulch	No Mulch
Nitrates	30	Trace	10
Phosphates	3/4	3/4	3/4
Potassium	1/2	1/2	1/2

The pH. of the soil was measured at the same time as the quick soils analyses were taken. The pH. ranged from 5.4 to 5.6 with no change indicated because of the mulching effect.

EXPERIMENT III - 1951

MATERIALS AND METHODS

The materials used in this year were the same as those of the previous year with one exception. The tomato variety L-3700 strain I proved to be too irregular in size of plant within treatments and also the fruit was very irregular. The variety Early Alberta, which had proven to be stabilized as to type and vigour during tests at the University in 1950, was substituted. The area used for the plots was immediately adjacent to that of 1950.

The same methods of procedure were used as in the previous year. Additional data was sought by measurements of growth at the peak of vegetative development.

The weather during this season differed extremely from that of 1950. The records from the weather office at Edmonton indicated that there were only three occasions during the summer months when precipitation was not recorded over a span of five days. There was rain almost every day in the month of July and up until August 15.

Temperature records were limited by the unavailability of one of the two soil temperature thermographs used in 1950. Therefore temperatures were taken with readings from the direct reading dial thermometers set on three treatments on the pepper trials. These were taken as often as possible and at definite times during the day.

EXPERIMENT III RESULTS

The readings on the tensiometers mirrored the weather during this season.

Table VII. The Range of Tensiometer Readings in Cm./Hg. for June, July and August, 1951.

	Shavings Mulch	Paper Mulch	No Mulch
Lowest Reading	3	4	4
Highest Reading	6	7	15

The readings given in Table VII certainly indicated that there was no lack of moisture for crop growth during this season. Data showing moisture levels under the different treatments are represented graphically in Figure 10.

The temperature differences recorded during this season, meagre as they had to be, indicated a small but obvious increase in temperature under the paper as compared with no mulch, during those days when sunshine was recorded. The temperatures under the shavings mulch were 10 to 15 degrees F. colder than the other treatments. Table VIII summarizes these temperature readings.

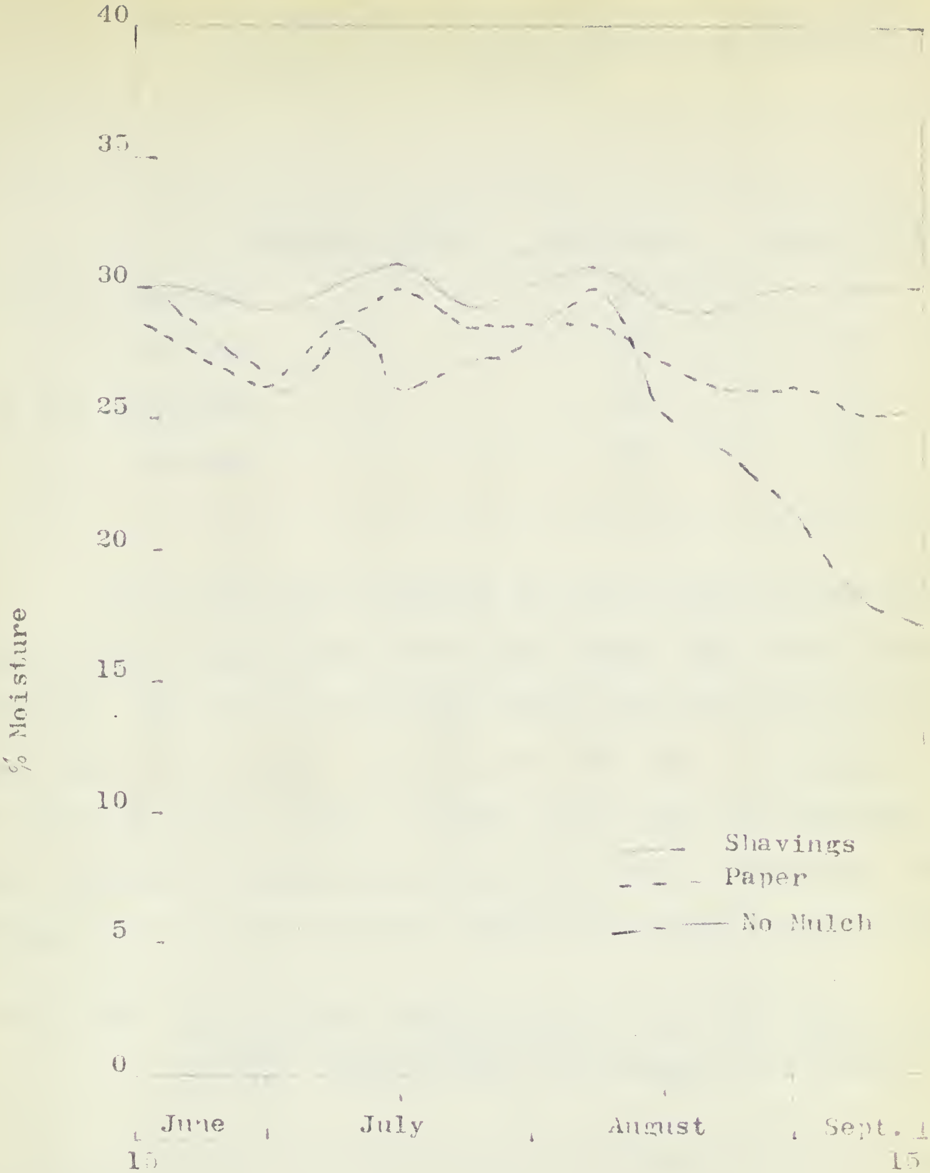

Fig. 10. A comparison of soil moisture levels, cucumber crop 1951. Data evolved from tensiometer readings.

Table VIII. Average Soil Temperatures at 3 Inch Level for the 1951 Growing Season, in Degrees C. Average of 14 Readings.

	Shavings Mulch	No Mulch	Paper Mulch
9 a.m. readings	13	17	18
1 p.m. readings	14	19	21
4 p.m. readings	15	19	22
9 p.m. readings	14	18	20

The quick soil analyses for 1951 again showed that nitrates under paper mulch were much higher than those under no mulch. The level of nitrates under paper was 30 p.p.m. or more, while those under the no mulch were near 10 p.p.m.. The shavings plots showed a higher level than the previous year. However, a depressing effect was still indicated. The averages of the soil analysis results are shown in Table IX.

Table IX. The Average Levels in p.p.m. of Nitrates, Phosphates and Potassium at Peak of Vegetative Growth, Season 1951, an Average of 18 Tests.

	Paper Mulch	Shavings Mulch	No Mulch
Nitrates	30	5	10
Phosphates	3/4	3/4	3/4
Potassium	1/2	1/2	3/4

The differences between plant growth on paper and "no mulch" were quite obvious with all three kinds of vegetables. A pictorial comparison of the differences exhibited on cucumber and pepper plots is given in Figures 11 and 12.

The measurements taken on plant growth were analyzed statistically. The averages for the vine length of cucumbers are shown in Table X. The complete Statistical Analysis is presented in Appendix II.

Table X. Vine length of Cucumbers in Inches, 1951 season. The Mean of Six Replications.

Paper Mulch	No Mulch	Shavings Mulch
25.56	18.52	5.63

F. value for treatments - 112.80.

Value needed for significance 5% - 4.10, 1% - 7.56.

L.S.D.# - ± 4.26 at the 1% level.

The results of the analysis of variance show a significant F. value well above the one percent level of significance. The L.S.D. was calculated to obtain more definite information on the differences between treatments. Therefore, by referring to Table X it may be said that, if no mulch is used as the normal treatment, then the vine length of cucumbers on paper mulch and shavings mulch differ significantly from this normal. These differences therefore result from the practice of mulching.

Least Significant Differences.

Fig. 11. Cucumber plots July 1951, showing the differences in plant growth between the treatments, paper mulch, no mulch, and shavings mulch.

Fig. 12. Pepper plots July 1951, showing the differences in plant growth between the treatments, paper mulch, no mulch, and shavings mulch.

There were two measurements of growth taken on the tomatoes and peppers. These were height and spread. These average values are shown for peppers in Tables XI and XII. The complete Statistical Analyses are presented in Appendix III and IV.

Table XI. Height of Peppers in Inches, Season 1951. The Mean of Six Replications.

Paper Mulch	No Mulch	Shavings Mulch
6.1	4.9	2.7

F. Value for treatments - 25.13

Value needed for Significance 5% - 4.10,1% - 7.56.

L.S.D. - $\pm$ 1.55 for 1%
- $\pm$ .98 for 5%.

Table XII. Spread of Peppers in Inches, Season 1951. The Mean of Six Replications.

Paper Mulch	No Mulch	Shavings Mulch
8.3	6.2	2.8

F. Value obtained for treatments - 50.56

Value needed for Significance 5% - 4.10,1% - 7.56

L.S.D. - 1.78 at the 1% level.

The L.S.D. shows that the height and spread of the peppers on the paper mulch and the shavings mulch differed significantly from the no mulch. These differences, therefore, result from the practice of mulching.

Tables XIII and XIV show the mean values for the height and spread of tomatoes. The complete statistical analyses are presented in Appendix V and VI.

Table XIII. The Height of Tomatoes in Inches, Season 1951. The Mean of Six Replications.

Paper Mulch	No Mulch	Shavings Mulch
18.3	16.2	9.8

F. value obtained for treatments - 103.51

F. value needed for significance - 5% - 4.10,1% - 7.56

L.S.D. - $\pm$1.93 at the 1% level.

Table XIV. The Spread of Tomatoes in Inches, Season 1951. The Mean of Six Replications.

Paper Mulch	No Mulch	Shavings Mulch
24.7	19.5	10.5

F. value obtained for treatments - 227.89

F. value needed for significance - 5% - 4.10,1% - 7.56

L.S.D. - $\pm$ 2.12 at the 1% level.

The results of the analysis of variance show a significant F. value above the one percent level. Both of the L.S.D. indicate that the spread and height of tomatoes on paper mulch and shavings mulch differ significantly from the normal no mulch treatment. These differences are therefore the result of the mulching practice.

Yields were taken on cucumbers, and these were limited to those cucumbers which had reached a marketable size for this slicing variety. Table XV shows the mean yields on the three treatments. The complete statistical analyses are presented in Appendix VII.

Table XV. Yields on Cucumbers in lbs. per Plot, Season 1951. The Mean of Six Replications.

Paper Mulch	No Mulch	Shavings Mulch
9.35	3.31	0

As there was no yield obtained from the shavings plots, this treatment was thrown out for purposes of analysis.

F. value obtained for treatment - 37.60

F. value needed for significance - 5% - 6.61, 1% - 16.26

This highly significant F. value indicates that the paper mulch yields differed from the no mulch yields. These differences, therefore, are the result of the practice of paper mulching.

No ripe tomato yields were obtained, owing to the poor weather for ripening which persisted during this season. Green yields were recorded just before the first frost. Only those tomatoes considered marketable in size were harvested. The complete statistical analyses are presented in Appendix VIII.

Table XVI. Yields of Green Tomatoes in lbs. per Plot, Season 1951. Mean of Six Replications.

Paper Mulch	No Mulch	Shavings Mulch
20.5	14.4	2.8

F. value obtained for treatment - 129.8

F. value needed for significance - 5% - 4.10,1% - 7.56

L.S.D. - $\pm$ 3.62at the 1% level.

The F. value obtained is highly significant. The L.S.D. indicates that both mulch treatment yields differ significantly from the no mulch yields. Therefore, these differences may be said to be the result of the mulching practice.

DISCUSSION OF RESULTS

Mulching and Soil Moisture

The mulched soils were found to be consistently higher in moisture content than the bare soil. Especially was this so with the shavings mulch, under which the soil was sticky wet at all times. The moisture effects of the paper mulch and no mulch treatments showed little difference. There is a possibility, however, that such differences as did exist might have proven to be larger if the moisture determinations had been taken closer to the surface of the soil than the five inch depth arbitrarily chosen. Smith (42) suggested that the paper mulch conserves moisture near the surface only. He considered that the paper mulch effect upon moisture conservation did not extend below the four inch level in soil so treated. During the experiment reported herein, it was observed that the plant roots under the paper were very close to the surface, and in some instances, the roots actually were exposed when the paper was lifted. This is a definite indication at least, that the paper mulch kept the soil surface moist enough to support root growth.

Mulching and Soil Temperature

It was found that the paper mulch increased the soil temperature under it, as much as 10 degrees F. above that of the bare soil. These increases were shown to be irregular,

apparently being dependent more upon general weather fluctuations than upon day and night differences in air temperature. the 1950 season was dry, and provided an unusual amount of sunny weather. During this summer the paper vs. no mulch differences registered were quite large. The 1951 season, however, had exactly opposite weather trends. The increases registered during the latter summer were small, and much of the time the soil temperatures, under paper and in the bare soil, were almost the same. Only on clear, sunny days were there increases under the paper to compare with those noted during the previous growing season. The shavings mulch plots were decidedly cooler than the other two treatments in all three years. McCalla (30) relates this decrease in temperature to the reflection of the sun's rays by the light coloured mulch materials.

The results relating to mulch influence on soil temperature demonstrate the importance of radiations from the sun and the efficiency of the mulch material in absorbing, or reflecting, heat rays from that source.

Mulching and Plant Nutrients

The soil analysis indicated a favourable effect upon soil nitrates due to paper mulching (see Tables VI and IX). Lyon and Buckman (27) state that the optimum temperature range for nitrate production was between 80 and 90 degrees F.. Therefore, the nitrate increase demonstrated earlier in this thesis may have been the result of more nearly optimum soil

temperatures under paper. The shavings mulch was found to depress soil nitrates greatly. A number of workers (2,6,27,33,) have considered this effect to be the direct result of adding cellulose material to the soil. Turk and Partridge (47) however, found that a mulch of gravel also could depress soil nitrates. In the trials reported here, moreover, shavings were not mixed with the soil but were laid on the surface. Thus, it may be that some factor other than the addition of cellulose caused the depression of nitrates already mentioned. It might be considered that the combined conditions of high moisture and low temperature under the mulch resulted in a poor physical soil nature. If this is so, the lack of aeration might be the main factor causing the nitrate depression under shavings. On the other hand, the cold wet environment may well have seriously reduced the activity of bacteria responsible for nitrification, as is observed commonly in bog areas.

Mulching and Plant Development

Obvious growth differences were observed under the three treatments. Most noticeable was the very poor growth of all three crops on the shavings plots. Unquestionably, some factor or factors resulted in soil conditions not conducive to normal plant development under this type of mulch. As already shown, soil temperatures under shavings were very much lower than those taken under the bare soil. The highest temperature recorded under the shavings in any of the three years was 59 degrees F.. No doubt the lower temperature retarded the

growth processes of these warm season crops. As an additional effect, the relatively high surface moisture would reduce aeration and generally affect the plant soil environment adversely.

Several investigators have suggested that wood shavings may contain substances toxic to plant growth. In the Edmonton trials, although normal vegetative and reproductive growth did not take place under shavings, and the plants were unthrifty in appearance, they were all living at the end of each season and showed no observable symptoms of poisoning. Harris (18) used shavings with strawberries, and found no harmful effects. Indeed, he reported an increase in growth and fruiting in the year following the application. A difference in chemical content of shavings from different species could, of course, account for differences in apparent toxicity where contrary effects are demonstrated.

In each of the three seasons, observations in the field indicated that the growth of plants on paper mulched plots was noticeably more vigorous than on either the unmulched soil or the shavings mulch. In 1951 the measurements taken at or near the peak of vegetative growth were analyzed statistically. The results of these analyses bear out the indications of the visual observations, and differences between all treatments, and with all crops, were significant above the one percent level. This suggests very emphatically that mulching with black paper has had a favourable effect upon the growth of the three warm season crops used in these experiments. True, only data for the year 1951 is presented, but when it is considered that

unseasonably cool weather prevailed during the 1951 summer, fullest confidence can be placed in the statistical results obtained.

Mulching and Fruit Development

Cucumbers showed a definitely favourable effect upon marketable yield, due to the paper mulching treatment. Tomatoes also showed significant differences in yield of "green ripe" fruit between treatments. There was no indication that any of the crops on paper mulch ripened earlier than those on unmulched soil. This is contrary to the observations of Flint (15) who reported definite encouragement of early maturity of a large number of vegetables by the use of paper mulch. It is probable that paper mulching has a complex influence upon plant development, only part of which encourages early maturity. It may well be, that under different conditions of day length hours of sunlight, and levels of air temperature than those prevailing in Alberta during the seasons involved, maturity of fruits would be advanced by the use of paper mulch.

GENERAL SUMMARY AND CONCLUSIONS

An attempt has been made to evaluate the general effects of mulching three warm season vegetable crops with asphalt sheathing paper and wood shavings. Plant and fruit development, as well as soil temperature and moisture, have been studied in some detail. The results of treatments on a randomized block field design using tomatoes, peppers and cucumbers as crop plants and continued for three seasons, are summarized below.

The records taken for soil moisture show that the shavings mulch kept the soil very moist, and that paper mulch was intermediate, between shavings and bare soil, in conserving soil moisture in the surface six inches.

The use of paper mulch stabilized and raised soil temperatures compared to those of the bare soil. This was a marked effect, which was in obvious contrast to the plots under shavings, wherein soil temperatures were stable enough but continuously lowest during the growing season.

The measurements of plant growth in 1951, which were analyzed statistically, indicate definitely that there was a very favourable effect upon plant growth by the paper mulch, and that the effect of shavings mulch definitely reduced plant growth.

Quick soil analyses for soil nitrates, phosphates and potassium showed that paper mulching increased nitrates considerably while the shavings mulching depressed them to a

very marked degree. No differences in soil phosphates and potassium were noted between treatments.

Yield data taken from the 1951 cucumber and tomato plots show definitely that paper mulching increased the yield of both these crops. In most cases, shavings mulching had such an unfavourable effect upon plant development, that no yields were recorded. There was no indication that the use of paper mulch influenced the maturing of cucumber or tomato fruits.

Generally, the results show that the use of paper mulch has a decidedly favourable influence on soil moisture and temperature. The combination of higher soil moisture and soil temperature might be considered to be the main factor causing the increase in available nitrates, and the increase in growth and fruiting, which occurred on the paper mulch plots during 1951. Conversely, it is suggested that the combination of higher soil moisture and lower soil temperature on the shavings plots resulted in an unfavourable soil environment. An attending result was that soil nitrates were reduced and general plant development was greatly retarded. No toxicity tests were made with the wood shavings, and no symptoms were observed on any plants that would suggest any thing other than poor general environment.

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APPENDIX I

Direct temperature readings for the 24 hour period, July 21m 1950, at 1 and 3 inch below surface, at surface level and at 4 feet above surface on the three treatments in degrees C.

Tomatoes

Time	Paper Mulch 1"	Paper Mulch 3"	Paper Mulch Level	No Mulch 1"	No Mulch 3"	No Mulch Level	Shavings Mulch 1"	Shavings Mulch 3"	Shavings Mulch Level	Air 4' Level
9 A.M.	23	19	38	22	17	38	17	13	30	29
11	23	19	42	22	17	45	15	14	46	30
1 P.M.	23	20	42	24	19	40	16	14	44	32
3	25	21	37	27	20	33	17	14	27	26
5	25	22	19	24	23	24	17	14	23	24
7	25	22	19	22	22	22	16	15	21	21
9	24	22	14	20	22	20	15	15	19	18
11	22	22	14	15	21	14	14	14	15	14
1 A.M.	20	20	13	15	19	13	14	14	14	13
3	19	20	10	16	18	12	14	14	8	12
5	17	19	15	15	17	15	14	14	14	16
7	18	18	17	17	17	18	14	14	16	16

Peppers

Time	Paper Mulch 1"	Paper Mulch 3"	Paper Mulch Level	No Mulch 1"	No Mulch 3"	No Mulch Level	Shavings Mulch 1"	Shavings Mulch 3"	Shavings Mulch Level	Air 4' Level
9 A.M.	24	19	39	19	17	40	14	13	40	29
11	25	20	42	24	19	42	15	14	42	30
1 P.M.	27	21	44	24	20	42	16	14	44	32
3	27	23	37	24	21	28	16	15	28	26
5	27	22	24	23	19	25	16	14	25	24
7	26	23	22	22	20	22	15	15	23	21
9	24	22	18	21	20	17	16	15	17	18
11	23	22	14	19	20	13	15	15	12	13
1 A.M.	19	22	13	17	19	12	15	15	12	13
3	19	20	10	17	18	9	14	14	11	12
5	18	20	15	16	17	15	14	14	15	16
7	18	19	17	16	17	18	14	14	16	16

Cucumbers

Time	Paper Mulch 1"	Paper Mulch 3"	Paper Mulch Level	No Mulch 1"	No Mulch 3"	No Mulch Level	Shavings Mulch 1"	Shavings Mulch 3"	Shavings Mulch Level	Air 4' Level
9 A.M.	22	18	38	19	16	42	14	13	40	29
11	22	18	44	19	16	48	15	13	43	30
1 P.M.	28	23	36	24	19	37	15	15	36	32
3	28	23	28	24	22	28	15	15	26	26
5	28	23	26	24	20	24	15	15	24	24
7	23	23	22	25	23	22	15	14	20	21
9	24	23	18	20	20	17	15	14	16	18
11	22	24	12	19	20	11	14	14	12	13
1 A.M.	20	22	11	17	18	11	12	14	10	13
3	20	22	11	16	18	8	14	14	10	12
5	19	21	14	16	18	14	14	14	14	16
7	19	20	16	16	18	15	14	14	14	16

APPENDIX II

ANALYSIS OF VARIANCE - LENGTH OF VINE OF CUCUMBERS, 1951.

Replicate	Paper Mulch	No Mulch	Shavings Mulch	$\bar{X}R$.
1	30.3 #	18.1	5	17.80
2	26.8	19.5	8	16.10
3	24.9	22.5	4.45	17.28
4	21.8	16.65	3.9	14.12
5	19.7	15.09	4.12	12.97
6	29.91	19.25	8.28	19.15
$\bar{X}T$.	25.56	18.52	5.63	

Correction factor = $(298.25)^2 / 18 = 4941.84$

Summation $X^2 = 6313.43$

Total sum of squares = 6313.43 - 4941.84 = 1371.59

Replicate sum of squares = 5031.78 - 4941.84 = 89.94

Treatment sum of squares = 6169.11 - 4941.87 = 1227.24

Error sums of squares = 1371.56 - (89.98 + 1227.24) = 54.34

Source of Variance	D.F.	S.S.	M.S.	F.	5%	1%
Total	17	1371.56				
Replicate	5	89.98	17.99	3.30	3.33	5.64
Treatment	2	1227.24	613.62	112.80	4.10	7.56
Error	10	54.34	5.44			

Least Significant Differences:

L.S.D. (Treatments) = (1.345)(3.169) = $\pm$ 4.26

each number represents 10 measurements on each plot.

APPENDIX III

ANALYSIS OF VARIANCE - HEIGHT OF PEPPERS, 1951.

Replicate	Paper Mulch	No Mulch	Shavings Mulch	$\bar{X}$R.
1	6.4#	5.0	2.2	4.5
2	7.3	3.5	2.3	4.4
3	6.6	5.5	2.9	5.0
4	4.8	4.7	2.6	4.0
5	5.9	4.8	2.9	4.5
6	5.3	6.3	3.0	4.9
$\bar{X}$T.	6.1	4.9	2.7	

Correction factor = $(82)^2/18$ = 373.56

Summation X^2 = 418.78

Total sums of squares = 418.78 - 373.56 = 45.22

Replicate sums of squares = 375.36 - 373.56 = 1.80

Treatment sums of squares = 409.75 - 373.56 = 36.19

Error sums of Squares = 45.22 - 37.99 = 7.23

Source of Variance	D.F.	S.S.	M.S.	F.	5%	1%
Total	17	45.22				
Replicate	5	1.80	.36	.50		
Treatment	2	36.19	18.10	25.13	4.10	7.56
Error	10	7.23	.72			

Least Significant Differences:

L.S.D. (Treatments) at 1% level =(.49)(3.169) = ± 1.55
L.S.D. (Treatments) at 5% level =(.49)(2.000) = ± .98

each number represents 16 measurements on each plot.

APPENDIX IV

ANALYSIS OF VARIANCE - SPREAD OF PEPPERS, 1951.

Replicate	Paper Mulch	No Mulch	Shavings Mulch	$\overline{X}$R.
1	8.8#	6.8	2.9	6.1
2	9.1	4.3	2.6	5.3
3	9.1	5.5	2.6	5.7
4	7.3	6.3	2.7	5.4
5	7.9	6.5	2.8	5.7
6	7.3	7.7	3.0	6.0
$\overline{X}$T.	8.3	6.2	2.8	

Correction factor = $(103.2)^2/18$ = 591.68

Summation X^2 = 694.62

Total sums of squares = 694.62 - 591.68 = 102.94

Replicate sums of squares = 593.21 - 591.68 = 1.53

Treatment sums of squares = 683.70 - 591.68 = 92.02

Error sums of squares = 102.64 - 93.55 = 9.09

Source of Variance	D.F.	S.S.	M.S.	F.	5%	1%
Total	17	102.64				
Replicate	5	1.53	.31	.34		
Treatment	2	92.02	46.01	50.56	4.10	7.56
Error	10	9.09	.91			

Least Significant Differences:

L.S.D. (Treatments) =(.55)(3.169) = 1.78

each number represents 16 measurements on each plot.

APPENDIX V

ANALYSIS OF VARIANCE - HEIGHT OF TOMATOES, 1951.

Replicate	Paper Mulch	No Mulch	Shavings Mulch	$\bar{X}R.$
1	20.2#	15.9	11.8	15.9
2	19.5	15.1	10.6	15.1
3	17.5	15.5	8.9	13.6
4	18.1	17.0	8.6	14.5
5	18.0	17.7	9.8	15.2
6	17.0	16.0	9.8	14.2
$\bar{X}T.$	18.3	16.2	9.8	

Correction factor = $(267.0)^2/18$ = 3960.50

Summation X^2 = 4211.36

Total sums of squares = 4211.36 - 3960.50 = 250.86

Replicate sums of squares = 3968.28 - 3960.50 = 7.78

Treatment sums of squares = 4192.36 - 3960.50 = 231.86

Error sums of squares = 250.86 - 239.86 = 11.00

Source of Variance	D.F.	S.S.	M.S.	F.	5%	1%
Total	17	250.86				
Replicate		7.78	1.55	1.38		
Treatment		231.86	115.93	103.51	4.10	7.56
Error		11.00	1.10			

Least Significant Differences:

L.S.D. (Treatments) = (.61)(3.169) = $\pm$ 1.93

each number represents 8 measurements on each plot.

APPENDIX VI

ANALYSIS OF VARIANCE - SPREAD OF TOMATOES, 1951.

Replicate	Paper Mulch	No Mulch	Shavings Mulch	$\bar{X}R.$
1	25.8#	20.3	13.0	19.7
2	25.8	18.8	10.8	18.5
3	23.8	17.7	8.0	16.5
4	23.8	19.8	10.6	14.7
5	24.1	20.3	12.3	18.9
6	24.9	20.6	8.6	18.0
$\bar{X}T.$	24.7	19.5	10.5	

Correction factor = $(329.0)^2/18$ = 6013.88

Summation X^2 = 6659.54

Total sums of squares = 6659.54 - 6013.88 = 645.66

Replicate sums of squares = 6030.52 - 6013.88 = 16.64

Treatment sums of squares = 6629.40 - 6013.88 = 615.52

Error sums of squares = 645.66 - 632.16 = 13.50

Source of Variance	D.F.	S.S.	M.S.	F.	5%	1%
Total	17	645.66				
Replicate	5	16.64	3.32	2.45		
Treatment	2	615.32	307.66	227.89	4.10	7.56
Error	10	13.50	1.35			

Least Significant Differences:

L.S.D. (Treatments) = (.67)(3.169)= 2.12

each number represents 8 measurements on each plot.

APPENDIX VII

ANALYSIS OF VARIANCE - CUCUMBER YIELDS, 1951.

Replicate	Paper Mulch	No Mulch	Shavings Mulch	$\bar{X}R$.
1	12.75 #	2.75	0	7.75
2	13.31	5.69	0	9.50
3	9.75	5.56	0	7.60
4	5.81	2.38	0	4.09
5	5.50	0	0	2.75
6	9.90	3.50	0	6.70
$\bar{X}T$.	9.35	3.31	0	

As there was no yield obtained on the shavings mulch, this treatment was thrown out. For the purpose of this analysis, only the two treatments, paper mulch and no mulch, will be considered.

Correction factor = $(76.0)^2/12$ = 481.33

Summation X^2 = 668.6

Total sums of squares = 668.6 - 481.33 = 187.27

Replicate sums of squares = 544.61 - 481.33 = 63.28

Treatment sums of squares = 590.77 - 481.33 = 109.44

Error sums of squares = 187.27 - 172.72 = 14.56

Source of Variance	D.F.	S.S.	M.S.	F.	5%	1%
Total	11	187.27				
Replicate	5	63.28	12.65	4.35	5.05	10.97
Treatment	1	109.44	109.44	37.60	6.61	16.26
Error	5	14.56	2.91			

each number represents the yield in lbs. from each plot.

APPENDIX VIII

ANALYSIS OF VARIANCE - GREEN TOMATO YIELDS, 1951.

Replicate	Paper Mulch	No Mulch	Shavings Mulch	$\bar{X}$R.
1	18#	13	2	11
2	26	16	3	15
3	18	14	2	11.3
4	22	14	3	13
5	19	14	3	12
6	20	15.5	4	13
$\bar{X}$T.	20.5	14.4	2.8	

Correction factor = $(226.5)^2/18$ = 2850.13

Summation X^2 = 3873.25

Total sums of squares = 3873.25 - 2850.1 = 1032.28

Replicate sums of squares = 2882.42 - 2850.13 = 32.29

Treatment sums of squares = 3816.7 - 2850.13 = 966.66

Error sums of squares = 1032.88 - 998.95 = 33.93

Source of Variance	D.F.	S.S.	M.S.	F.	5%	1%
Total	17	1032.88				
Replicate	5	32.29	6.46	1.64		
Treatment	2	966.66	483.33	129.8	4.10	7.56
Error	10	33.93	3.39			

Least Significant Differences:

L.S.D. (Treatments) = (1.145)(3.169) = ± 3.62

each number represents the yield in lbs. from each plot.